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(54) A method and apparatus for driving a semi-conductor laser device.

(57) A method and apparatus for driving a semiconductor laser device (SLD1) in a laser recorder to produce a substantially constant optical power output over a range of temperatures while preserving a high optical switching frequency. A semiconductor laser device (SLD1) and a current sink (SLD2) are used in combination in driver circuit. A bias current (Ib1) maintains the semiconductor laser device (SLD1) at a first operating state, below a selected optical power threshold, and another bias current (Ib2) maintains the current sink (SLD2) at a first state also below a selected threshold. An information current (Im) is added to the bias current (Ib1) to drive the semiconductor laser device (SLD1) at a second state having a higher optical power. The information current (Im) is then steered to the current sink (SLD2), adding to the other bias current (Ib2), to drive the current sink (SLD2) at a second state such that the semiconductor laser device (SLD2) returns to the first state. A feedback signal (E1) adjusts the information current (Im) according to the output power of the semiconductor laser device (SLD1) when operating at the second state and according to the conditions of the current sink (SLD2).

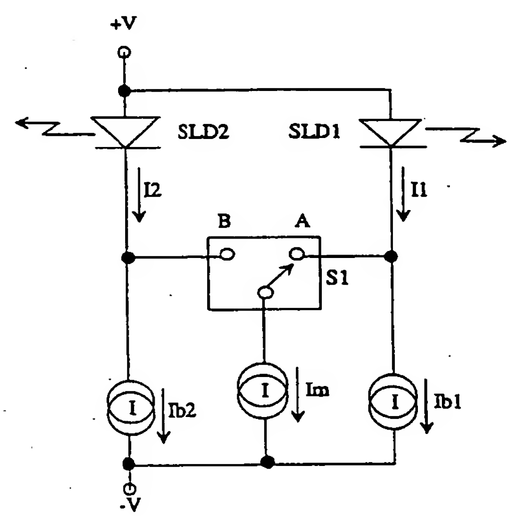

Fig. 1

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The invention relates generally to a method and apparatus for current driving a semiconductor laser device for producing an optical signal. Specifically the method and apparatus provide a bias current that produces a low laser power output and a higher current that produces a higher laser power output.

Semiconductor laser devices emit light having an optical power output level that is a non-linear function of the current flowing through the device. The transfer function, device current versus optical power output, of semiconductor laser devices is not stable and changes as a function of temperature and age. These devices must be controlled to maintain a desired optical power output level and insure that the electrical power dissipation does not exceed its rated maximum and destroy the device. These devices are capable of high switching frequencies when maintained in a conducting state by supplying a bias current through the device. The bias current reduces the effective impedance of the device thereby increasing its switching frequency.

Previous circuits lacked in maintaining constant ON state and OFF state currents through the semiconductor laser device. This causes the laser beam to be unstable, optical power output is not at the desired level immediately following the transition from the OFF state to the ON state. This instability causes optical power density variations which introduce noise into the optical output signal.

Another problem with prior circuits is poor ability to adjust and maintain the operating points of the current driver to compensate for variations in the terminal characteristics of the semiconductor laser device due to temperature variations and age.

For example, a driver circuit for a laser diode is described in U.S. Patent 4,761,659, issued on August 2, 1988, to Negishi. This driver circuit compensates for variation of the relationship of laser diode current and laser diode optical power output due to temperature and age. The driver circuit compensates for these variations by using a diode in a reference circuit for controlling the power output of the laser diode. The reference voltage, produced by the reference circuit, varies with temperature in a manner similar to that of the laser diode which tends to maintain the laser diode optical power output reasonably constant. The driver circuit itself however limits high frequency operation since there is no bias current supplied to the laser diode during its OFF state.

Another example is U.S. Pat. No. 4,709,369, issued on Nov. 24, 1987, to Howard. This patent describes a driver circuit that controls the power output of a laser diode. This driver circuit allows for a bias current through the laser diode for increased frequency of operation. The circuit adjusts the writing current and bias current levels with a single reference. This single reference is optimized to produce the desired power output in the writing state and the bias current is whatever results from the reference voltage through the other emitter resistor. This circuit does not maintain a constant contrast ratio between the ON and OFF states of the laser diode and can cause image shadow on sensitive imaging media as temperature varies.

It is therefore a general object of the invention to control the current flows within a semiconductor laser device to maintain a substantially constant optical power output while maintaining a high switching frequency of the semiconductor laser device.

It is a further object of the invention to automatically adjust the current flows within a semiconductor laser device to compensate for variations in the transfer characteristics of the device due to temperature and age in order to maintain the optical power output and contrast ratio substantially constant while maintaining the ability to switch the semiconductor laser device at a high frequency.

A method and apparatus for driving a semiconductor laser device that produces a high optical power output state and a low optical power output state in a semiconductor laser device. A bias current for a semiconductor laser device is established that produces a low predetermined optical power output defining its first state. A higher current that is the sum of the bias current and an information current produces a high predetermined optical power output defining its second state. The information current is maintained substantially constant via a closed loop control system. The information current is steered through one of two semiconductor laser devices in response to an input information signal.

Both of the bias currents are adjusted, by a calibration circuit, to compensate for changes in temperature to maintain the low predetermined optical power output level of each first state. This provides for a controlled contrast ratio which is substantially constant. The bias currents maintain the semiconductor laser devices in an active state such that a high switching frequency can be realized.

The calibration circuit also insures that the information current has substantially the same value regardless of the semiconductor laser device through which it is steered. This condition results in stable optical power output close to the switching time thereby minimizing noise in the optical signal and maintaining high switching frequency.

The objects and features set forth above and other objects and features of the invention will best be understood from a detailed description of a preferred embodiment thereof, selected for purposes of illustration and shown in the accompany-

ing drawings in which:

Fig 1 is a schematic diagram of the basic current steering circuit.

Fig 2 is a schematic diagram showing the addition of a control mechanism to adjust the information current source.

Fig 3 is a schematic diagram showing the addition of a control mechanism to adjust the bias currents for each of the semiconductor laser devices.

The preferred embodiment of the invention is in a laser imaging system wherein a laser beam is used to record an image on a recording media. A semiconductor laser device is used as the imaging element which generates the laser beam. A current generator is used to drive the imaging element with a substantially constant current. Another semiconductor laser device is used as a dummy load or current sink for the current generator when it is not driving the imaging element. This allows the current generator to drive the semiconductor laser devices and maintain the information current substantially constant. A current switch is responsive to an input information signal which is representative of an image to be recorded on a recording media. Such an information signal in the present invention may comprise an "on" command for each image pixel to be recorded and an "off" command for each unrecorded image pixel.

The basic circuit, as shown in Fig 1, is a differential switch that steers an information current (Im) between a first semiconductor laser device (SLD1) and a second semiconductor laser device (SLD2). Each semiconductor laser device is supplied a first and second bias current, (Ib1) and (Ib2), respectively, to keep them in a conducting state. The values of (Ib1) and (Ib2) are picked such that the optical power outputs of (SLD1) and (SLD2) are below the lasing threshold, or alternately, below a recording threshold, in an image recorder. The existence of the bias currents (Ib1) and (Ib2) reduces the time required for the semiconductor laser devices to transition between a first state, having an optical output power which is below a lasing or recording threshold and a second state, having an optical output power which is higher than the first state. When switch (S1) is in position (A), the information current (Im) is steered through semiconductor laser device (SLD1) such that (I1) = Ib1 + Im and (I2) = Ib2. This condition causes (SLD1) to be in its second state while (SLD2) is in its first state. When switch (S1) is in position B the current (Im) is steered through (SLD2) such that (I2) = Ib2 + Im and (I1) = Ib1. This condition causes (SLD2) to be in its second state while (SLD1) is in its first state. The position of switch (S1) changes in response to the state of the input information signal.

Fig. 2 shows the addition of a control mechanism to the basic circuit of Fig 1. This control circuit adjusts the information current (Im) to produce a higher predetermined optical power output defining the second state of semiconductor laser device (SLD1). A reference current source (Ir1), which has a predetermined value representative of the higher predetermined optical power output defining the second state of (SLD1), and a current source (If1), which is proportional to the optical power output of (SLD1) is added to the circuit of Fig. 2. The current source (If1) in the present invention is a photodiode contained within the same package as the laser diode (SLD1).

A portion of the laser optical output power directed onto the photodiode produces a current which is proportional to the laser optical output power. In an alternative embodiment, the current source (If1) may comprise a photodiode external to the laser cavity having a portion of the laser output optical signal focused onto the photodiode surface by an optical system.

The currents (Ir1) and (If1) are summed and supplied to an error amplifier (A1) via the (A) position of switch (S2). The error amplifier (A1) produces an error signal (E1) which adjusts the value of the current source (Im) such that Ir1 - If1 = 0 which occurs when the optical power output of (SLD1) attains the predetermined value defining its second state. Switches (S1) and (S2) are interlocked such that they both change to the same position at the same time in response to the state of the input information signal. Since in the present invention, the predetermined value of the optical output power remains constant for each recording pixel, the recorded image is a halftone image.

A complementary circuit is added around semiconductor laser device (SLD2) . This circuit is comprised of a reference current source (Ir2) and a current source (If2), that is proportional to the optical power output of (SLD2). In the present invention, a photodiode contained within a laser diode package is used. The currents (Ir2) and (If2) are summed and supplied to the error amplifier (A1) via the B position of switch (S2). The error amplifier (A1) again produces an error signal (E1) which adjusts the value of the current source (Im) such that Ir2 - If2 = 0, which is the condition that occurs when the optical power output of (SLD2) attains the predetermined value of its second state.

The value of the current (Ib2) is picked such that the value of the information current (Im) is the same for both positions (A) and (B) of switches (S1) and (S2). This results in the optical power output of (SLD1) being immediately stable after the transition of switches (S1) and (S2) occurs. This condition greatly improves the usable switching frequency of the driver circuit.

Fig. 3 shows the addition of control circuitry to calibrate, adjust, the bias current sources for (SLD1) and (SLD2). This allows the driver circuit to compensate for device transfer characteristic variations with temperature and age. The desired result is to maintain the optical power output of (SLD1) substantially constant and maintain the value of (Im) substantially constant whether steered through (SLD1) or (SLD2).

The circuit of Fig. 3 replaces current source (Ir1), (of Fig. 2), with two current sources (Ira1) and (Irb1). The current sources (Ira1) and (Irb1) are reference currents for the higher predetermined optical power output defining the second state and the low predetermined optical power output defining the first state respectively of device (SLD1). An explanation of the calibration process follows.

The bias current (Ib1) is adjusted during a time when the optical output of (SLD1) is not otherwise used. During this time switches (S1) and (S2) are in position (N), switch (S5) is closed, switches (S4), (S6), (S7) and (S8) are open, and track and hold circuit (T/H1) is in the track mode. The current If1 - Irb1 is summed and input to error amplifier (A2) via switch (S5). The amplified error output of (A2) is tracked by track and hold circuit (T/H1). The output of (T/H1) adjusts the current (Ib1) such that If1 - Irb1 = 0, which occurs when (SLD1) attains the low predetermined optical power output defining its first state. Track and hold circuit (T/H1) switches from track mode to hold mode at the end of this time and remains in hold mode until the next calibration cycle.

After completing the adjustment of bias current (Ib1) the calibration process samples the value of (Im) when flowing through (SLD1). This is done to allow subsequent adjustment of the bias current (Ib2) such that (Im) remains substantially the same value when flowing through (SLD2). This sampling is performed during a time following the adjustment of bias current (Ib1). Switches (S1) and (S2) are placed in position A, switches (S4), (S6) are closed, switches (S5), (S7), (S8) are open and track and hold circuit (T/H2) is placed in track mode. A current mirror is used to mirror the value of the information current (Im) in the (Ims) current source. The current (Ims) is tracked by track and hold circuit T/H 2. The output of (T/H2) is the current source (Imt) which now has a value equal to that of (Ims). The sampling is now complete and (T/H2) is placed in hold mode until the next adjustment cycle.

After completing sampling of the value of the information current (Im) the calibration process adjusts the value of bias current source (Ib2). During this time switches (S1) and (S2) are in position B, switches (S5), (S6) are opened, switches (S4), (S7) and (S8) are closed, and track and hold circuit (T/H3) is placed in the track mode. This causes the information current (Im) to be adjusted by error amp (A1), which now has an input error current of If2 - Ir2, until the optical power output of (SLD2) attains the predetermined value defining its second state. The current (Ims) now mirrors the value of (Im) as it flows through (SDL2). The current Imt - Ims is formed via switch (S7) being closed and input to error amplifier (A3). Error amplifier (A3) amplifies the error current and drives track and hold circuit (T/H3). The output of track and hold circuit (T/H3) adjusts the current source (Ib2) such that Imt - Ims = 0, which is the condition that causes (Im) to be substantially the same value as when it was flowing through device (SLD1). Track and hold circuit (T/H3) is now placed in hold mode until the next calibration cycle. This ends this phase of adjustment and the calibration process.

The result of this process of adjusting the bias current (Ib2) accomplishes two desired effects. Firstly the value of (Im) is made to be substantially the same value when flowing through (SLD2) as when flowing through (SLD1). Secondly the contrast ratio is maintained substantially constant by adjusting the bias current (Ib1) to produce the low predetermined optical power output defining the first state of (SLD1).

The calibration cycle is periodically repeated to adjust the circuit for changes in the transfer characteristics of (SLD1) and (SLD2) due to temperature and age.

Having described in detail the preferred embodiment of the invention, it will now be apparent to those skilled in the art that numerous modifications can be made therein without departing from the scope of the invention as defined in the following claims.

Claims

1. A method for driving a semiconductor laser device (SLD1) between first and second states comprising the steps of:

(a) driving the semiconductor laser device (SLD1) with a bias current (Ib1) which produces a predetermined optical power output that defines said first state;

(b) driving said semiconductor laser device (SLD1) at a higher current produced by the combination of said bias current (Ib1) and an information current (Im), said higher current producing another predetermined optical power output that defines said second state;

(c) producing a transition from said second state to said first state by steering the information current (Im) to a current sink (SLD2) having substantially the same

switching speed and voltage versus current terminal characteristics as said semiconductor laser device (SLD1); and,
(d) producing a transition from said first state to said second state by steering said information current (Im) to said semiconductor laser device (SLD1).

2. The method of claim 1 further comprising the step of repeating steps (c) and (d) in response to an information signal.

3. The method of claim 2 wherein said information signal represents a halftone image.

4. The method of claim 2 wherein the optical power output of said second state of said semiconductor laser device (SLD1) is constant.

5. The method of claim 1 wherein said current sink (SLD2) has a bias current (Ib2) that maintains said information current (Im) substantially constant during the transition of step (c) and during the transition of step (d).

6. The method of claim 1 wherein said semiconductor laser device (SLD1) is a semiconductor laser diode.

7. The method of claim 1 wherein said current sink (SLD2) is a semiconductor laser diode.

8. The method of claim 2 wherein said information signal represents an image to be recorded on a recording media wherein said optical power output that defines said first state is below an image recording threshold of said recording media and said optical power output that defines said second state is above said image recording threshold.

9. The method of claim 1 wherein said information current (Im) is controlled by an error signal (E1), causing adjustment to said information current (Im) such that said second state optical power output level of said semiconductor laser device (SLD1) remains substantially constant.

10. The method of claim 9 wherein said error signal (E1) is proportional to a current produced by a semiconductor photodiode having a portion of said optical power output of said semiconductor laser device (SLD1) directed thereon to generate a current source (If1) from said semiconductor photodiode which is proportional to said optical power output of said semiconductor laser device (SLD1).

11. The method of claim 10 wherein said semiconductor photodiode is internal to said semiconductor laser device (SLD1).

12. The method of claim 10 wherein said semiconductor photodiode is external to said semiconductor laser device (SLD1) and a portion of said optical power output of said semiconductor laser device (SLD1) is directed onto said semiconductor photodiode by an optical system.

13. The method of claim 10 wherein the relationship of said current source (If1) versus said optical power output of said semiconductor laser device (SLD1) is stable over a range of operating temperatures.

14. The method of claim 1 wherein said information current (Im) and said predetermined optical power output are closed loop controlled by the steps of:
(a) providing a first current source (If1) having a current output which is proportional to the optical output signal amplitude of said semiconductor laser device (SLD1) when operating at said second state;
(b) providing a first reference current source (Ir1) having a current output which is equal to the value of said first current source (If1);
(c) providing a second current source (If2) having a current output which is proportional to the optical power output of said current sink (SLD2) when operating at said second state;
(d) providing a second current source (If2) having a current output equal to the current of said second current source (If2);
(e) adjusting said information current (Im) for driving said first semiconductor laser device (SLD1) according to an error signal (E1) which is proportional to the difference between the current output by said first current source (If1) and the current output by said first reference current source (Ir1) such that said second state of said semiconductor laser device (SLD1) produces a constant optical power output, and;
(f) adjusting said information current (Im) for driving said current sink (SLD2) according to an error signal (E1) which is proportional to the difference between the current output by said second current source (If2) and the current output by said second reference current source (Ir2) such that said second state of said current sink (SLD2) produces a constant optical power output.

15. The method of claim 2 further comprising the steps of:
(a) adjusting said bias current (Ib1) of said semiconductor laser device (SLD1) such that said semiconductor device (SLD1) produces said predetermined optical power output of said first state;
(b) adjusting said information current (Im) such that the sum of said information current (Im) and said bias current (Ib1) causes said semiconductor laser device (SLD1) to emit said predetermined optical power output of said second state; and,
(c) providing another bias current (Ib2) for said current sink (SLD2) such that the sum of said other bias current (Ib2) and said information current (Im) causes said current sink (SLD2) to emit said predetermined optical power output for said second state, and causes said information current (Im) to have substantially the same value as in step (b).

16. An apparatus for driving a semiconductor laser device (SLD1) between first and second states, said apparatus comprising:
(a) means for driving the semiconductor laser device (SLD1) with a bias current (Ib1) which produces a predetermined optical power output that defines said first state;
(b) means for driving said semiconductor laser device (SLD1) at a higher current produced by the combination of said bias current (Ib1) and an information current (Im), said higher current producing another predetermined optical power output that defines said second state;
(c) means for producing a transition from said second state to said first state by steering said information current (Im) to a current sink (SLD2) having substantially the same switching speed and voltage versus current terminal characteristics as said semiconductor laser device (SLD1); and,
(d) means for producing a transition from said first state to said second state by steering said information current (Im) to said semiconductor laser device (SLD1).

17. The apparatus of claim 16 wherein said means for producing said transition from said second state to said first state and said means for producing said transition from said first state to said second state are responsive to an information signal.

18. The apparatus of claim 17 wherein said information signal represents a halftone image.

19. The apparatus of claim 17 wherein the optical power output of said second state of said semiconductor laser device (SLD1) is constant.

20. The apparatus of claim 16 wherein said current sink (SLD2) has a bias current (Im2) which is adjusted to maintain said information current (Im) substantially constant during the transition from said second state to said first state and the transition from said first state to said second state.

21. The apparatus of claim 16 wherein said semiconductor laser device (SLD1) is a semiconductor laser diode.

22. The apparatus of claim 16 wherein said current sink (SLD2) is a semiconductor laser diode.

23. The apparatus of claim 17 wherein said information signal (Im) represents an image to be recorded on a recording media wherein said optical power output that defines said first state is below an image recording threshold of said recording media and said optical power output that defines said second state is above said image recording threshold.

24. The apparatus of claim 16 wherein said information current (Im) is controlled by feedback means for adjusting said information current (Im) such that said second state optical power output level of said semiconductor laser device (SLD1) remains substantially constant.

25. The apparatus of claim 24 wherein said feedback means is a semiconductor photodiode with a portion of said optical power output of said semiconductor laser device (SLD1) is directed onto said semiconductor photodiode thereby producing a current source (If1) which is proportional to said optical power output of said semiconductor laser device (SLD1).

26. The apparatus of claim 25 wherein said semiconductor photodiode is internal to said semiconductor laser device (SLD1).

27. The apparatus of claim 25 wherein said semiconductor photodiode is external to said semiconductor laser device (SLD1) and a portion of said optical power output of said semiconductor laser device (SLD1) is directed onto said semiconductor photodiode by an optical system.

28. The apparatus of claim 25 wherein said feedback means is stable over a range of operating

temperatures.

29. The apparatus of claim 16 wherein said information current (Im) and said predetermined optical power output are controlled by a closed loop system comprising:

(a) means for generating a first current (If1) proportional to the optical power output of said semiconductor laser device (SLD1) when operating at said second state;

(b) means for generating a first reference current (Ir1) having a value equal to the value of said first current (If1);

(c) means for generating a second current (If2) proportional to the optical power output of said current sink (SLD2) when operating at said second state;

(d) means for generating a second reference current (Ir2) having a value equal to the value of said second current (If2);

(e) means responsive to the difference between said first current (If1) and said first reference current (Ir1) for adjusting said information current (Im) for driving said semiconductor laser device (SLD1) such that said second state of said semiconductor laser device (SLD1) produces said constant predetermined optical power output; and,

(f) means responsive to the difference between said second current (If2) and said second reference current (Ir2) for adjusting said information current (Im) for driving said current sink (SLD2) such that said second state of said current sink (SLD2) produces said constant predetermined optical power output.

30. The apparatus of claim 17 further comprising:

(a) means for adjusting said bias current (Ib1) of said semiconductor laser device (SLD1) such that said semiconductor laser device (SLD1) produces said predetermined optical power output of said first state;

(b) means for adjusting said information current (Im) such that the sum of said information current (Im) and said bias current (Ib1) causes said semiconductor laser device (SLD1) to emit said predetermined optical power output of said second state; and,

(c) means for adjusting said other bias current (Ib2) of said current sink (SLD2) such that the sum of said other bias current (Ib2) and said information current (Im) causes said current sink (SLD2) to emit said predetermined optical power output of said second state, and causes said information current (Im) to have substantially the same value as said information current (Im) that when added to said bias current (Ib1) of said semiconductor laser device (SLD1) caused said semiconductor laser device (SLD1) to emit at said predetermined optical power output of said second state.

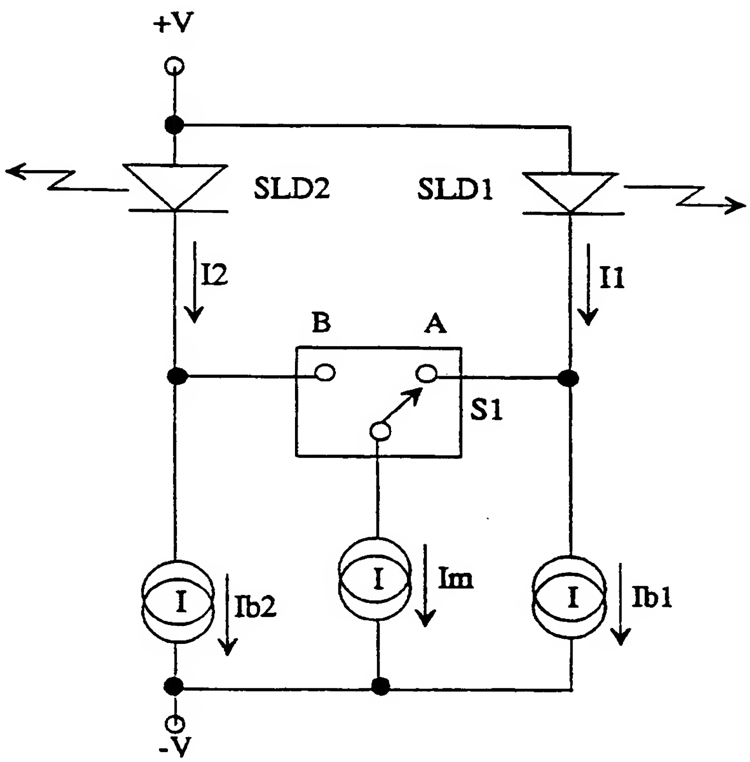

Fig. 1

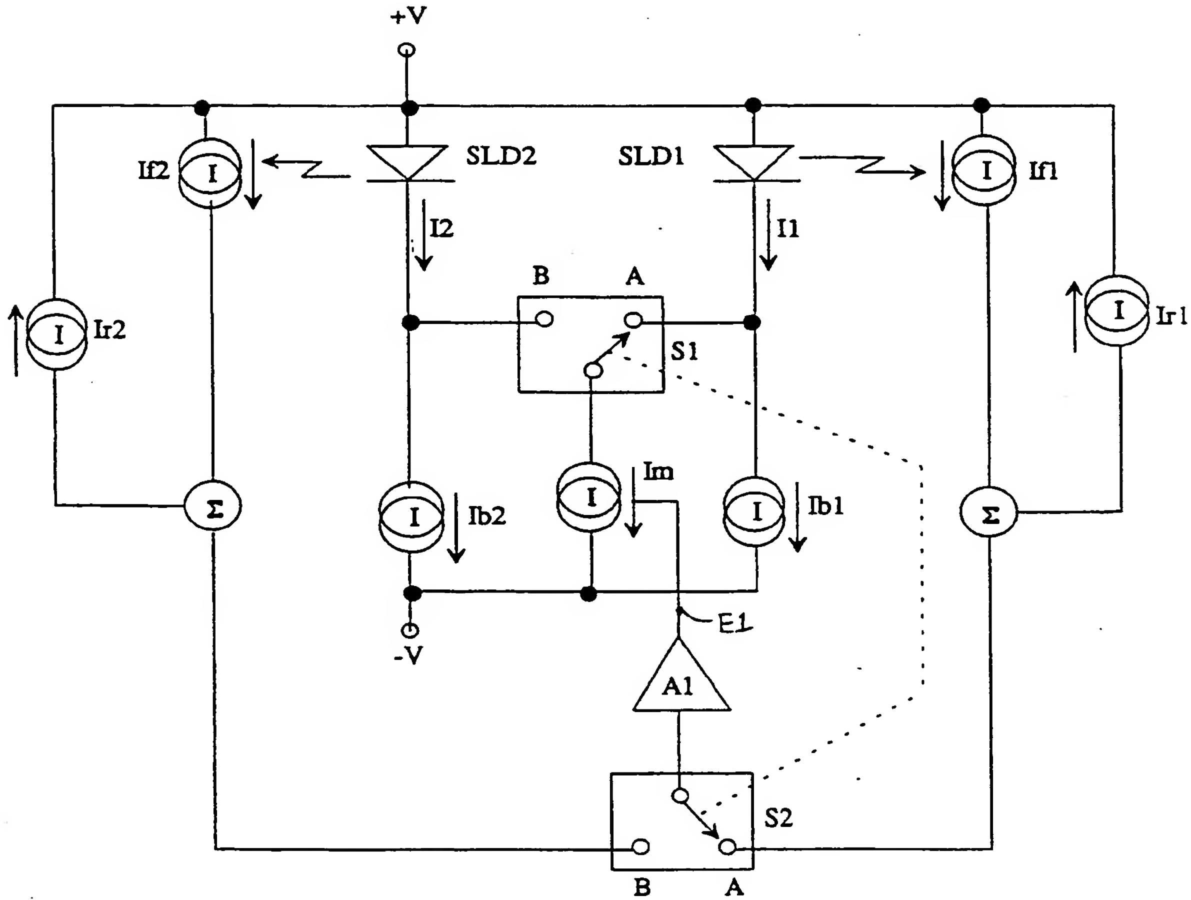
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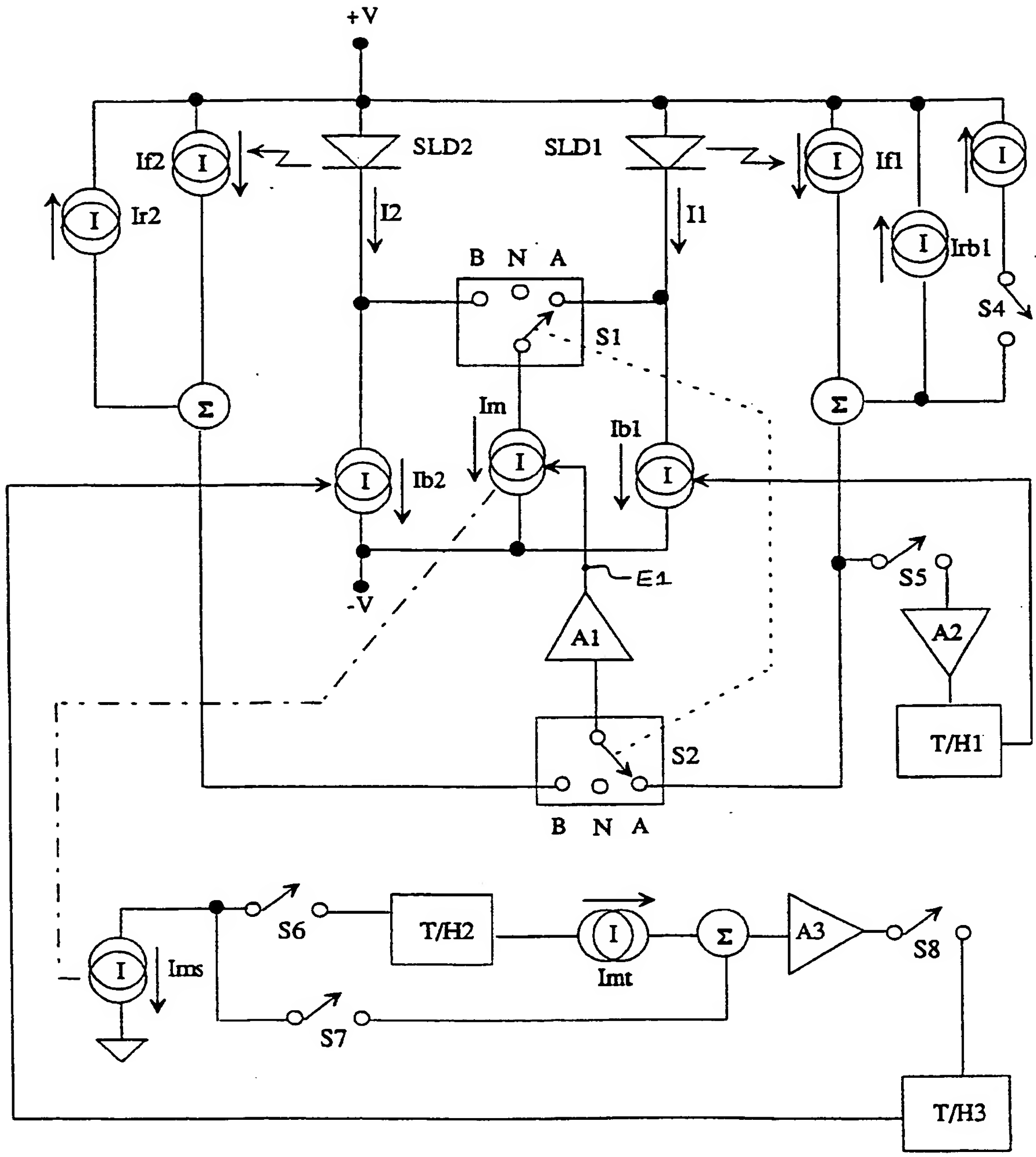
Fig. 2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-V
E1
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A2
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S2
B N A
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Imt
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S8
Ims
S7
T/H3

Fig. 3

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(54) A method and apparatus for driving a semi-conductor laser device

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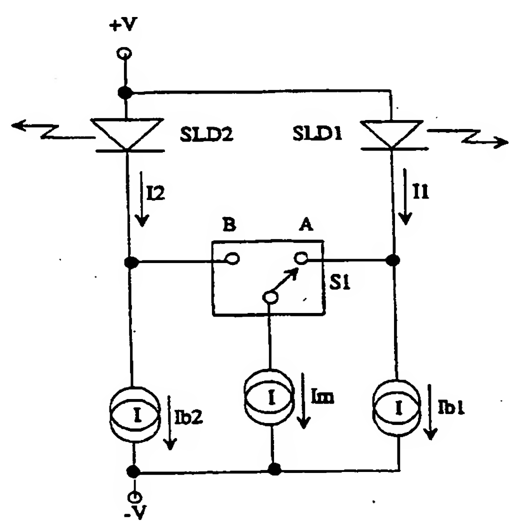

Fig. 1

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EUROPEAN SEARCH REPORT

Application Number
EP 94 12 0418

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	15 January 1996	Claessen, L

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